# PSC STAFF REPORT: THE WISCONSIN STRAY VOLTAGE EXPERIENCE

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## INTRODUCTION

The Public Service Commission of Wisconsin's (PSCW) Stray Voltage Analysis Team (SVAT) has been collecting data from its on-farm stray voltage investigations since the inception of the program in 1989. The major investor-owned utilities in Wisconsin have also recorded information from their stray voltage investigations at the request of the PSCW since 1988. The scope of the data collected by the utilities was enlarged some time in 1993 to correspond with the data collected by the SVAT. Unique to the SVAT portion of the database, additional information about the primary power delivery system, EMF measurements, and specific farm information are included.

The reader should note that this is not a random sample of Wisconsin farms. The investigations done by the utilities were nearly always done at the request of farm customers who were anxious about potential stray voltage concerns. The investigations performed by the SVAT were initiated only after a utility investigation had been completed and the farm customer was still unsure about potential stray voltage complications. Because this is not a true random sample, no conclusions can be drawn about the applicability of this data to the entire population of farms in Wisconsin.

For each investigation, data was recorded about the characteristics of the distribution system serving the farm including:

1. Date of testing and general location within Wisconsin,
2. Circuit miles from the farm to the distribution substation serving that farm,
3. Number of ground rods per mile near the farm,
4. Material and size of the primary phase and neutral conductors,
5. Primary phase voltage,
6. KVA rating of the primary transformer,
7. Number of phases serving farm, and
8. Primary system mitigation recommendations;

Data on characteristics of the farm including:

1. Herd size in number of milking cows,
2. Rolling herd average milk production (RHA) from the most recent test information,
3. Bulk tank average Somatic Cell Count from the most recent test,
4. If on DHIA management program, and
5. Specific mitigation existing and recommended;

and electrical measurements relating to the level of animal contact voltage/current present on the farm:

1. Maximum animal (cow) contact current reading,
2. Maximum value of the primary neutral to earth voltage,
3. Maximum value of the secondary neutral to earth voltage, and
4. Source resistance of the cow contact.

Stray voltage, in the PSCW docket 05-EI-106, has been defined as a measurement of 1.0 milliamp of 60 Hertz (Hz), steady state, root mean square (rms) current flowing in a cow contact area (a 0.5-Volt rms potential across a nominal 500 ohm resistance simulating a cow). This is further defined as a "level of concern," at which level action should be taken to reduce cow contact current to below 1 milliamp. The PSCW "level of concern" for confined farm animals is a conservative, preventive level, below the point where moderate avoidance behavior is likely to occur and well below where a cow's behavior or milk production would be harmed. Note that the standard is for farm animals in confinement areas and does not refer to humans in the same environment. The standards refer strictly to 60 Hz alternating current (AC) rms steady state voltage or current and not to any harmonic content that may or may not be present in addition to the fundamental frequency. Other electrical phenomena that are not included in any PSCW orders are medium frequency transients (>3 kHz) and radio frequency (RF)-source transients (>500 kHz) induced from sources outside the distribution power system including currents in the earth. The cow contact area is defined as any area where a cow could simultaneously contact two conducting surfaces having a difference in electrical potential. The test methods used to measure primary, secondary, and cow contact voltages are well defined by the PSCW. Utility investigators have been made aware of these standardized procedures through various educational efforts conducted by the PSCW and the University of Wisconsin beginning in 1989. In some instances, a spot check was performed on the farm, and the entire data set was not completed for that investigation. Linear regression analysis was performed to determine possible correlation between variables. A significance test was also performed. Only complete data sets for a farm investigation were used to avoid potential influence on cross correlations.

## THE TYPICAL FARM

Figure 1 in the Appendix presents the data on a "typical" farm with and without measured and documented stray voltage present. Figure 1 presents the average, standard deviation, sample size and range for each of the parameters listed. The data represents all farms investigated by SVAT and the reporting utilities in a combined database. The typical farm with no documented stray voltage, i.e. below the PSCW "level of concern" (cow contact measurement from 1.0 microamp to 999 microamps), has an average herd size of 62 cows with an average rolling herd average production of 17,714 pounds and a somatic cell count of 367,000. The average measurement of cow contact current as 0.32 milliamp. The primary profile of the utility's distribution system near the farm has a ground rod resistance of 73 ohms and a ground rod current of 33 milliamps. On the farm itself, the average primary neutral to reference voltage (Vpnref) reading is 0.83 volts while the average secondary neutral to reference voltage (Vsnref) reading is 0.85 volts. The main complaints registered by the farmer in his application for a formal stray voltage investigation, in decreasing order of frequency, are an increased somatic cell count, uneven milkout, nervous cows, reduced milk production, and milk letdown concerns. The average electro-magnetic field (EMF) reading in the barn is 0.69 milligauss. This level of EMF exposure is very low and typical of background levels in occupied dwellings.

For farms with stray voltage above the "level of concern," (i.e. cow contact current above 1 milliamp), the average herd size is 54 cows with an average rolling herd average production of 17,278 pounds and a somatic cell count of 423,000. The average cow contact current is 2.04 milliamps, with a median of 1.45 milliamps. The primary profile has an average ground rod resistance of 102 ohms and a rod current of 40 milliamps. On the farm, the Vpnref is 1.32 volts while the Vsnref is 1.92 volts. The main farmer complaints, in order of decreasing frequency, are increased somatic cell count, reduced milk production, nervous cows, uneven milkout, and increased clinical mastitis. The average EMF reading in the barn is 0.61 milligauss.

## COW CONTACT CURRENT VERSUS DISTANCE TO SUBSTATION

Figure 2 contrasts the magnitude of maximum cow contact current (milliamps) with the circuit miles from the farm to the substation that feeds power to the farm. The data consists of 1090 points ranging from 0.3 miles to 43 miles from farm to substation. The cow contact current varies from 1.0 microamp to 19 milliamps. The correlation coefficient (r squared) was 0.00031, with a p-value for the significance of the correlation of 0.85 indicating no correlation between the parameters. There have been concerns raised over the years that location on the distribution line, i.e. being an end of line customer for instance, was related to the probability that the customer had stray voltage. This data shows that there is no significant relationship between cow contact current and distance from the substation.

## COW CONTACT CURRENT VERSUS GROUNDS PER MILE

Figure 3 contrasts the magnitude of the cow contact current with the number of ground rods per mile from the farm towards the substation. The number of grounds per mile is related to the effective resistance to ground of the primary distribution system. The number of ground rods varies from a minimum of 3 to a maximum of 23. The number of data points shown is 1090. The correlation coefficient (r squared) was 0.0032 and with a p-value of 0.06 which indicates no correlation between the parameters. However, this approaches significance at the 95 percent level and the trend agrees with circuit theory, the more grounds per mile, the lower the resistance; hence the lower the primary neutral voltage given similar loads. The fact that the correlation explains less than 1 percent of the variation indicates that there are other factors of far greater importance influencing cow contact currents.

## COW CONTACT CURRENT VERSUS PRIMARY NEUTRAL CONDUCTOR SIZE

The data of Figure 4 compares the nominal resistance, in the first mile from the farm, of the primary neutral conductor with the magnitude of the average cow contact current. This nominal resistance (in ohms per mile) is determined by two factors, namely the wire gauge and the material from which the conductor is made. The correlation coefficient (r squared) was 0.0124 with a p-value of 0.0002, which indicates a significant correlation between the parameters at the 95 percent level, but a very low correlation coefficient. The primary neutral conductor size explains only 1 percent of the variation in cow contact currents. The graph is based on 1089 data points.

## COW CONTACT CURRENT VERSUS PRIMARY LINE VOLTAGE MAGNITUDE

Figure 5 compares the average cow contact current with the magnitude of the primary distribution line voltage. There are 1089 points of data represented in the graph. The data shows a trend indicating that higher primary line voltages produce lower cow contact current measurements. The correlation coefficient (r squared) was 0.0047 with a p-value of 0.024, again indicating a significant correlation between the parameters at the 95 percent level, but a very low correlation coefficient.

## COW CONTACT CURRENT VERSUS PRIMARY TRANSFORMER KVA RATING

Figure 6 contrasts average cow contact current and the kVA rating of the primary to secondary transformer. As a general rule, the larger the herd size, the larger the transformer rating will be to supply power to the farm. The data consists of 854 points with transformer sizes ranging from 10 kVA to

75 kVA. The average cow contact current varies from 0.74 milliamps to 1.37 milliamps. The correlation coefficient (r squared) was 0.0013 with a p-value of 0.30, which indicates no significance. As the graph illustrates, no clear trend is apparent.

## COW CONTACT CURRENT VERSUS PRIMARY NEUTRAL TO REFERENCE VOLTAGE

The dependence of cow contact current to the primary neutral to reference voltage (Vpnref) is illustrated in Figure 7. Note that there are many points clustered in a narrow range of from 0.25 to 2.0 volts. The correlation coefficient (r squared) was 0.19 with a p-value of less than 0.001, which indicates significance. There is correlation, as expected from circuit theory, between the primary neutral to reference voltage and the cow contact current. The regression equation is cow contact current (CCA) = 0.155 + 0.563*Vpnref. The data is based on 1088 points.

## COW CONTACT CURRENT VERSUS SECONDARY NEUTRAL TO REFERENCE VOLTAGE

The data of Figure 8 shows the relationship between cow contact current and the farm's secondary neutral to reference voltage (Vsnref). The graph appears very similar to the previous one for primary neutral to reference voltage. It is based on 1088 points. The average cow contact current is 0.76 milliamps. The correlation coefficient (r squared) was 0.25, with a p-value of less than 0.001 indicating significance. There is a similar correlation between Vsnref and the cow contact current. The regression equation is cow contact current (CCA) = 0.09+ 0.62*Vsnref.

## STRAY VOLTAGE SOURCE VERSUS POWER PROVIDER

Figure 9 is based strictly on the investigations done by the SVAT. This graph compares the various power suppliers: municipal utilities, investor-owned utilities (IOUs) and electric cooperatives; and the sources of stray voltage if more than 1.0 milliamp. There are three sources of stray voltage. If present, stray voltage may be solely due to the power suppliers system or it may be solely the result of on-farm (secondary) conditions. It can also be due to a combination of these two sources in varying proportions. Of the documented cases where the contribution from the primary distribution system to cow contact current was equal to or more than 1.0 milliamp, 69 percent were served by an electric cooperative and 23 percent were served by an IOU. In those cases where the contribution from on-farm sources was greater than or equal to 1.0 milliamp, 62 percent were associated with IOUs and 31 percent were associated with electric cooperatives. In those cases where the stray voltage equaled or exceeded 1.0 milliamp from a combination of the two sources, 69 percent were served by electric cooperatives and 25 percent were served by IOUs. In those cases where cow contact current was less than 1.0 milliamp, 40 percent were served by electric cooperatives and 57 percent were served by lOUs.

Figure 10 provides more detail on the cow contact current levels, the sources of the current, and the power providers. As an example, for cow contact currents greater than 1.0 milliamp, and the source being the primary neutral, the average of cow contact currents for IOU's is 1.9 with a standard deviation of 0.77, with 6 cases ranging from 1 to 3 milliamps.

## HERD SIZE VERSUS COW CONTACT CURRENT

Figure 11 compares the size of the herds in the sample to milliamps measured in the cow contact area. Most of the data is clustered in the area of herd sizes of less than 100 cows and cow contact currents of less than 2 milliamps. The correlation coefficient (r squared) was 0.008, with a p-value of 0.004, which indicates some significance, but little correlation. While there may be a slight trend in the data, it does not explain a meaningful percentage of the variations.

## ROLLING HERD MILK PRODUCTION VERSUS COW CONTACT CURRENT

The data shown in Figure 12 contrasts a farm's rolling herd average milk production and its measured cow contact current. The correlation coefficient (r squared) was 0.0047 indicating very little correlation with a p-value of 0.0361 indicating significance. The number of data points was 929. The results were reevaluated removing the lower 15 percent and the top 5 percent of the data points. The correlation coefficient then became 0.0013 with the p-value becoming 0.333 indicating no significance. The number of data points was 743. By analyzing a subset of the database, the results shifted from being significant to being non-significant. The possible correlation is, in any case, weak with 99.5 percent of the variation in RHA explained by other factors.

## SOMATIC CELL COUNT VERSUS COW CONTACT CURRENT

The data shown in Figure 13 contrasts by the bulk tank average somatic cell count with cow contact current. The correlation coefficient (r squared) was 0.003, which indicates very little correlation with a p-value of 0.09, which indicates no significance. The number of data points was 929. The results were reevaluated removing the lower 15 percent and the top 5 percent of the data points. Using this subset of data changed the correlation coefficient to 0.0073, indicating no correlation, with a change in the p-value to 0.02, indicating significance. The number of data points was 744. By using a subset of the database, the results shifted from being non-significant to being significant, the opposite of what transpired with the rolling herd average. The correlation is, in any case, very weak with 99.3 percent of the variations explained by other factors.

## CONCLUSIONS

More than 90 percent of the farms in this data set had cow contact currents less than 2 mA, AC, 60 Hz, rms and more than 70 percent had less than 1 mA, AC, 60 Hz, rms. The low cow contact currents are likely attributable to efforts by utilities in response to the PSCW's regulatory and educational efforts. Correlation was found between both the primary neutral voltage and the secondary neutral voltage and the cow contact current, as expected. There was no meaningful correlation between cow contact currents and either milk production or somatic cell count. No other effects such as those of working or keeping animals in an electrical environment were investigated. The distribution of variables measured by the SVAT and IOU investigators compared well.

**TYPICAL FARM PROFILE WITH AND WITHOUT STRAY VOLTAGE PRESENT**

| PARAMETER | NO STRAY VOLTAGE PRESENT .001 < Icc < .999 | STRAY VOLTAGE PRESENT 1.0 < Icc | UNITS |
|---|---|---|---|
| DISTANCE TO SUBSTATION | 5.5 ± 3.3 (945, 0.3 – 33) | 5.6 ± 3.8 (371, 0.2 – 43) | MILES |
| GROUNDS PER MILE | 11.3 ± 3.4 (873, 3 – 27) | 10.9 ± 3.5 (367, 1.5 – 27) | GND/MI |
| NEUTRAL CONDUCTOR OHMS PER MILE | 1.92 ± 1.27 (965, 0.27 – 7.33) | 2. 29 ± 1.40 (377, 0.28 – 14.6) | OHMS |
| Vpnref | 0.88 ± 0.72 (890, 0.01 – 5.96) | 1.82 ± 1.40 (354, 0.13 – 10.9) | VOLTS |
| Vsnref | 0.85 ± 0.67 (870, 0.01 – 5.24) | 1.92 ± 1.46 (345, 0.01 – 12.0) | VOLTS |
| Icc | 0.32 ± 0.26 (1012, 0.001 – 0.98) | 2.04 ± 2.01 (Median=1.45) (383, 1.0 – 19.8) | MILLIAMPS |
| HERD SIZE | 62 ± 49 (907, 9 – 860) | 54 ± 26 (339, 3 – 240) | COWS |
| MILK PRODUCTION | 17714 ± 3288 (706, 1200 – 27000) | 17278 ± 3248 (257, 7000 – 26000) | POUNDS |
| SOMATIC CELL COUNT (X 1,000) | 367 ± 259 (830, 40 – 3000) | 428 ± 417 (313, 60-5800) | |

FORMAT: AVERAGE ± STANDARD DEVIATION
(NUMBER OF POINTS, MINIMUM – MAXIMUM)

**FIGURE 1**

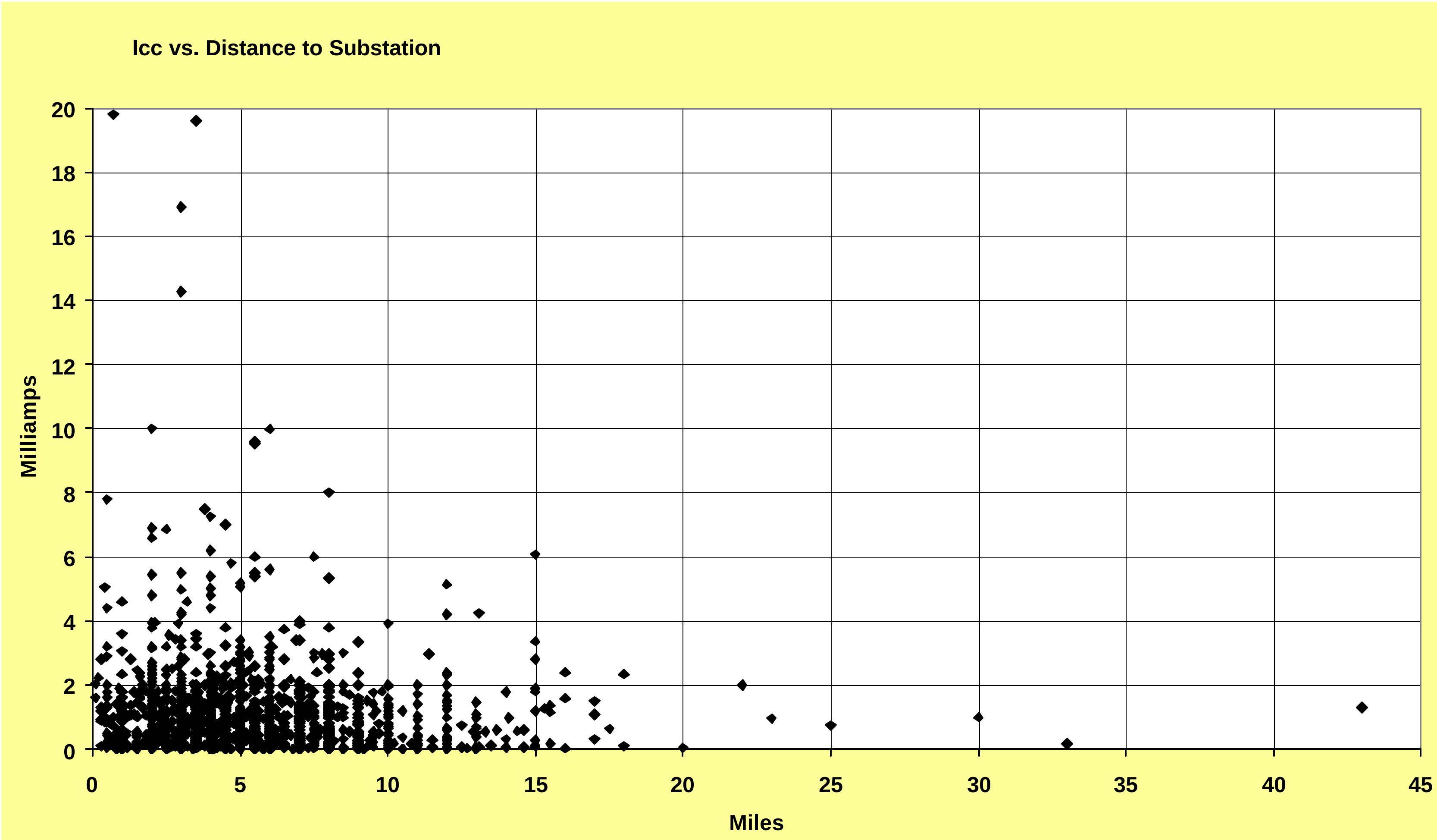

Icc vs. Distance to Substation
Milliamps
Miles
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30
35
40
45

**FIGURE 2**

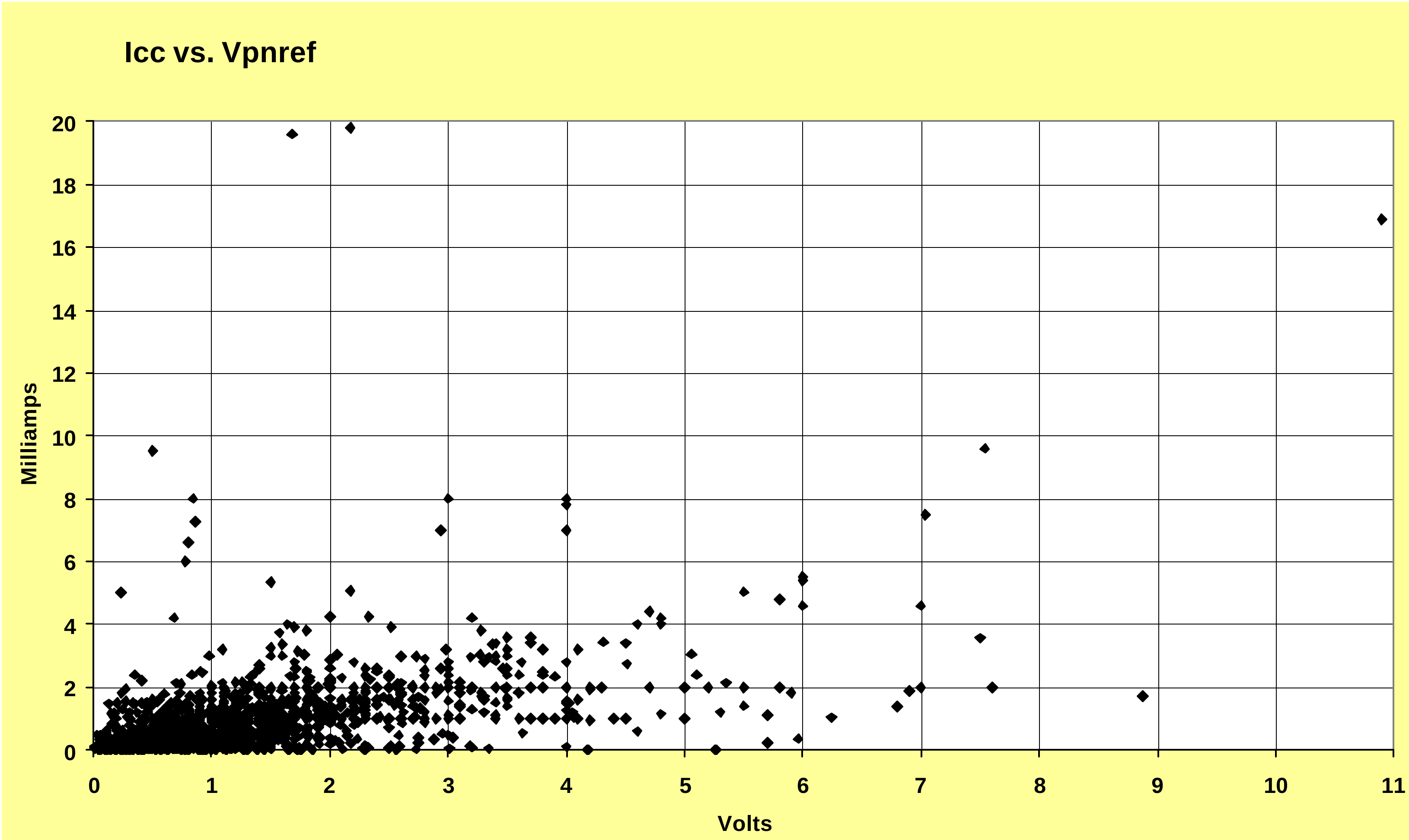

Icc vs. Vpnref
Milliamps
0
2
4
6
8
10
12
14
16
18
20
0
1
2
3
4
5
6
7
8
9
10
11
Volts

**FIGURE 3**

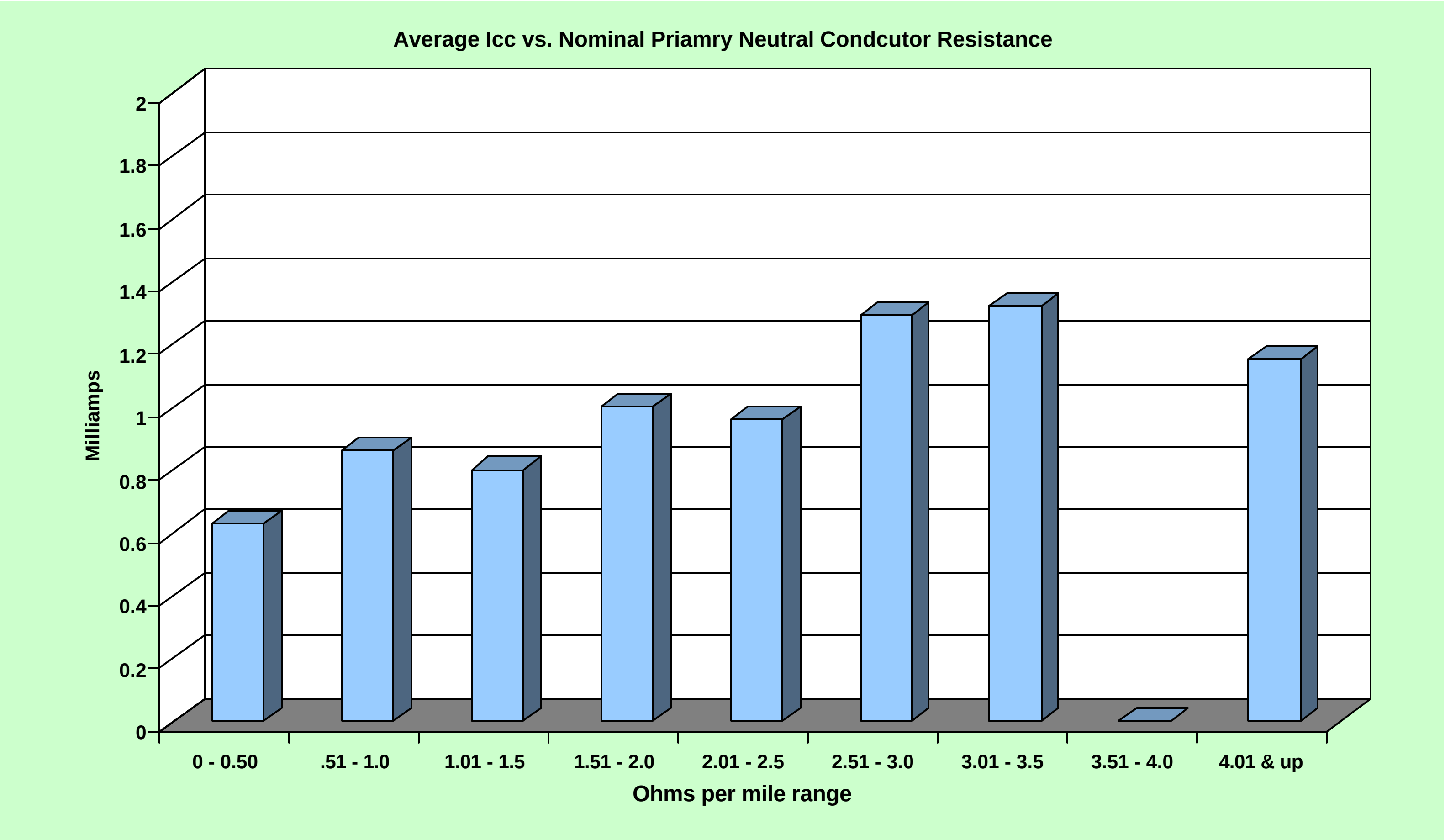

Average Icc vs. Nominal Priamry Neutral Condcutor Resistance
Milliamps
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0 - 0.50
.51 - 1.0
1.01 - 1.5
1.51 - 2.0
2.01 - 2.5
2.51 - 3.0
3.01 - 3.5
3.51 - 4.0
4.01 & up
Ohms per mile range

**FIGURE 4**

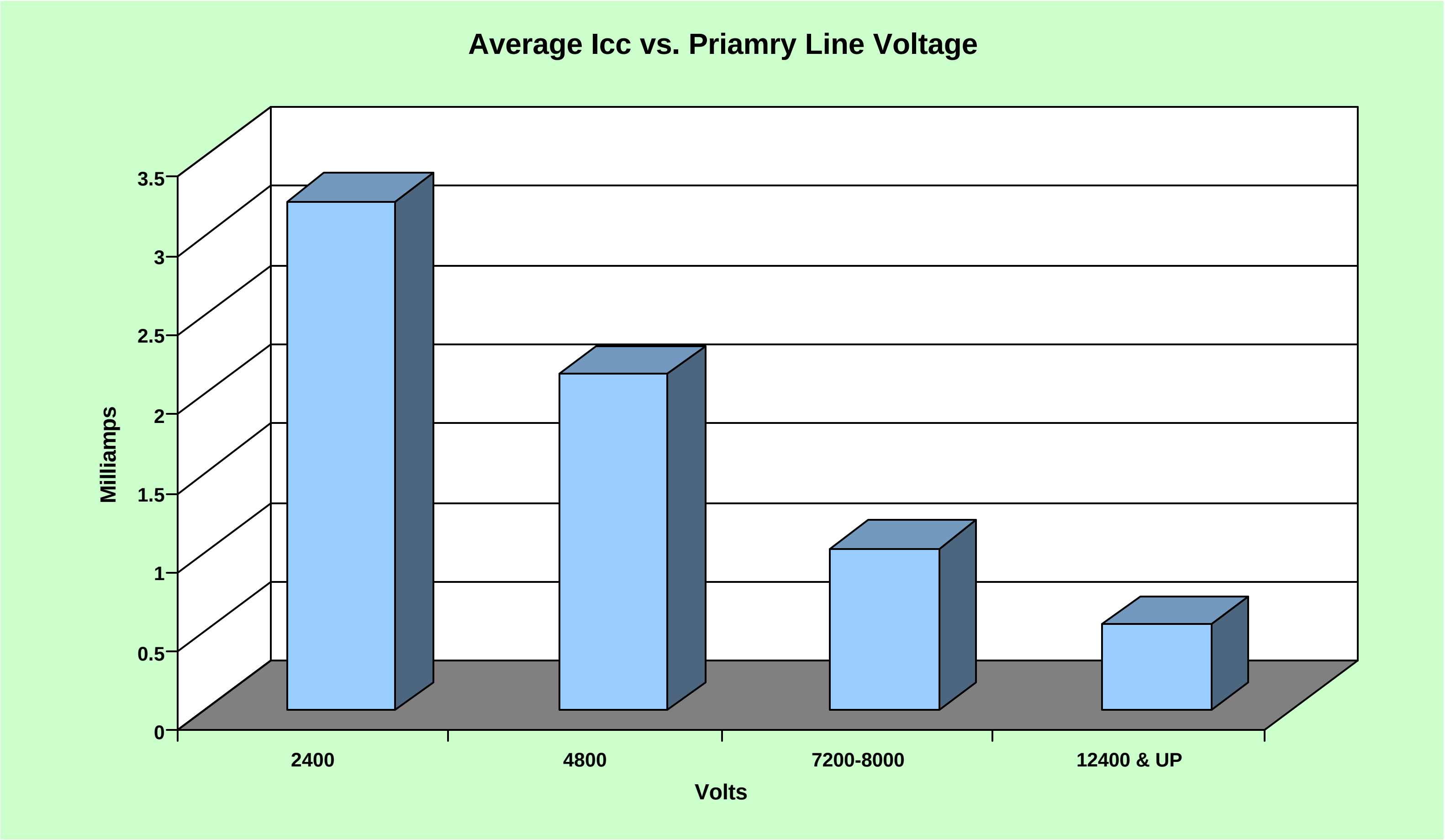

Average Icc vs. Priamry Line Voltage
Milliamps
0
0.5
1
1.5
2
2.5
3
3.5
2400
4800
7200-8000
12400 & UP
Volts

**FIGURE 5**

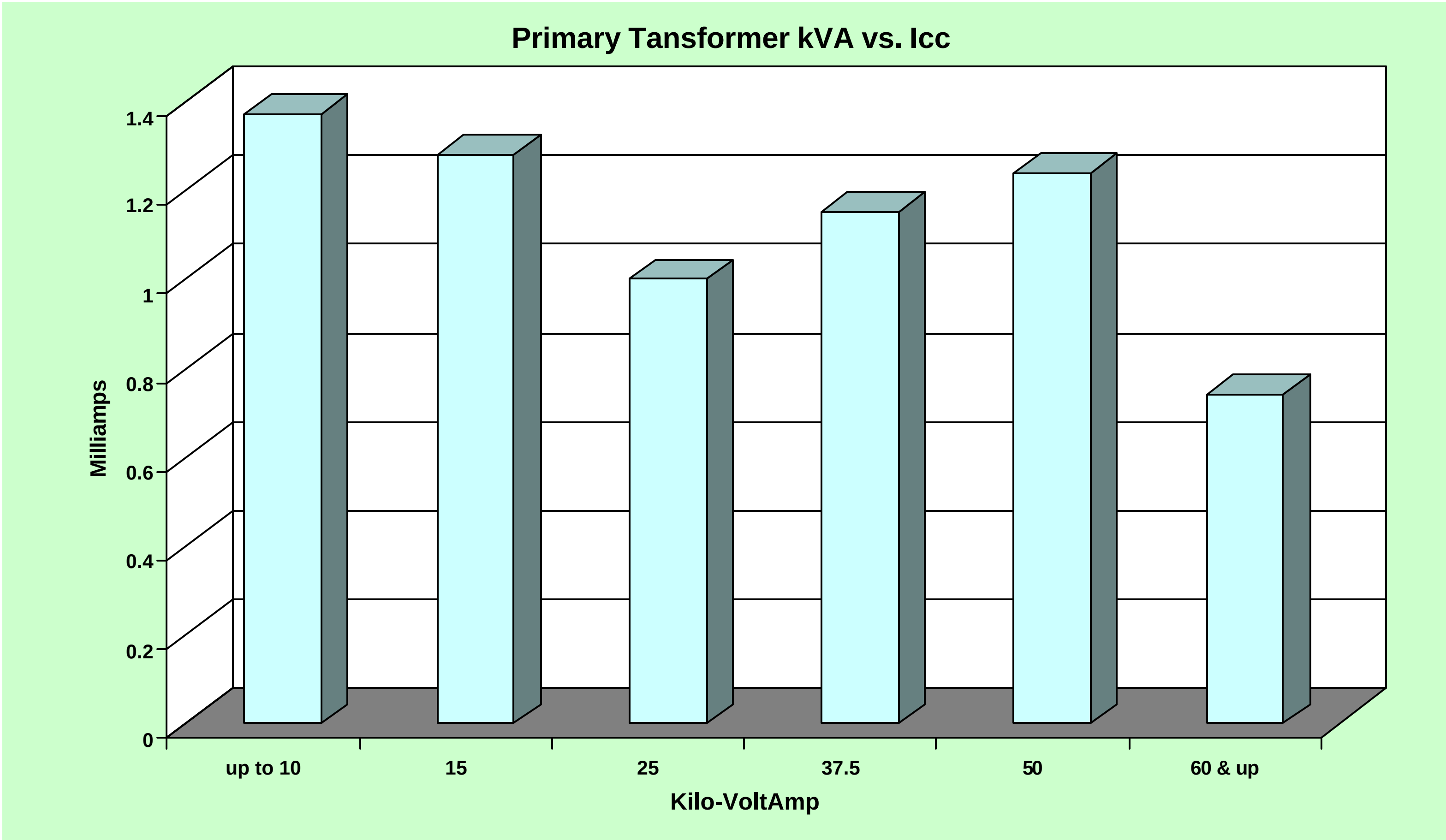

Primary Tansformer kVA vs. Icc
Milliamps
1.4
1.2
1
0.8
0.6
0.4
0.2
0
up to 10
15
25
37.5
50
60 & up
Kilo-VoltAmp

**FIGURE 6**

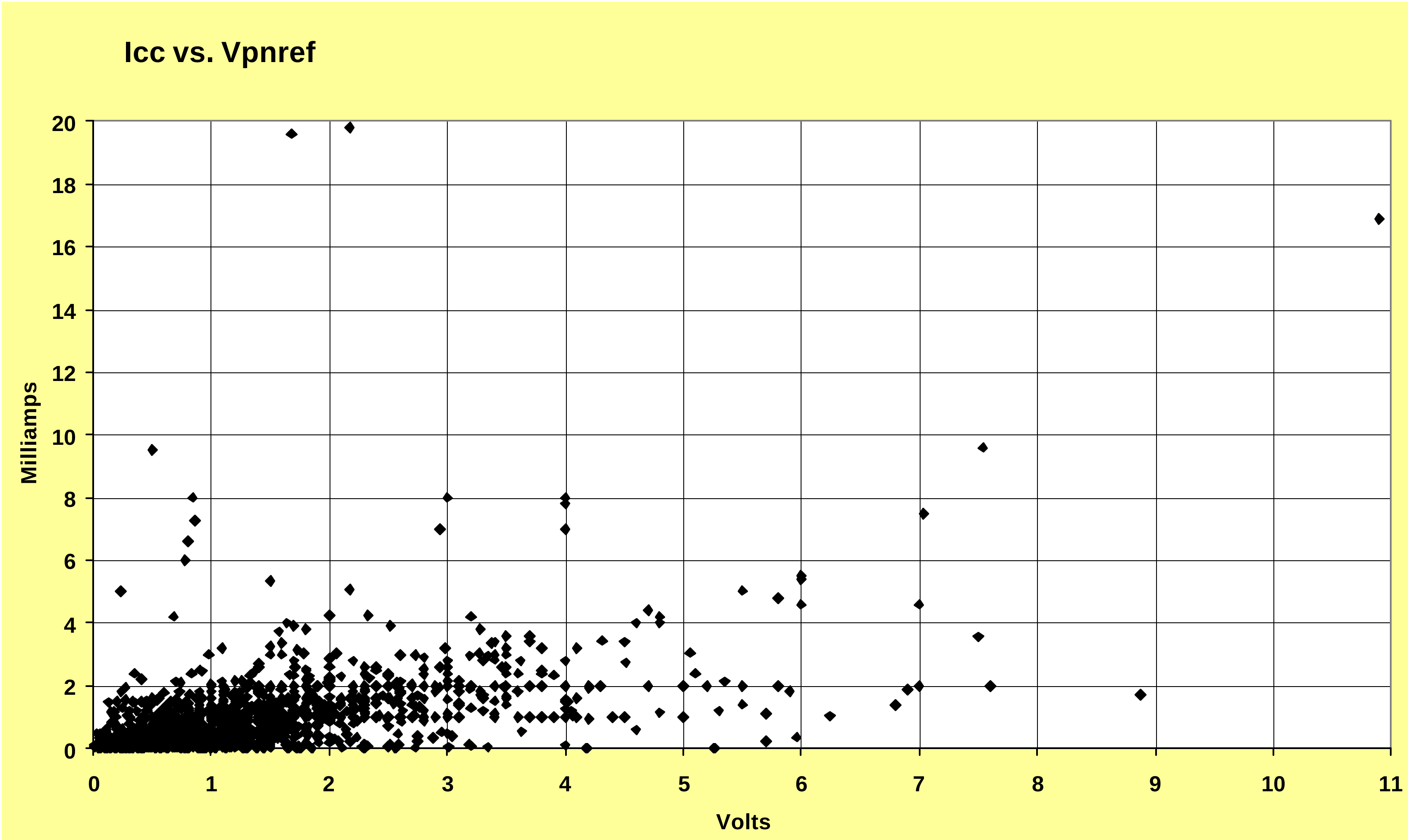
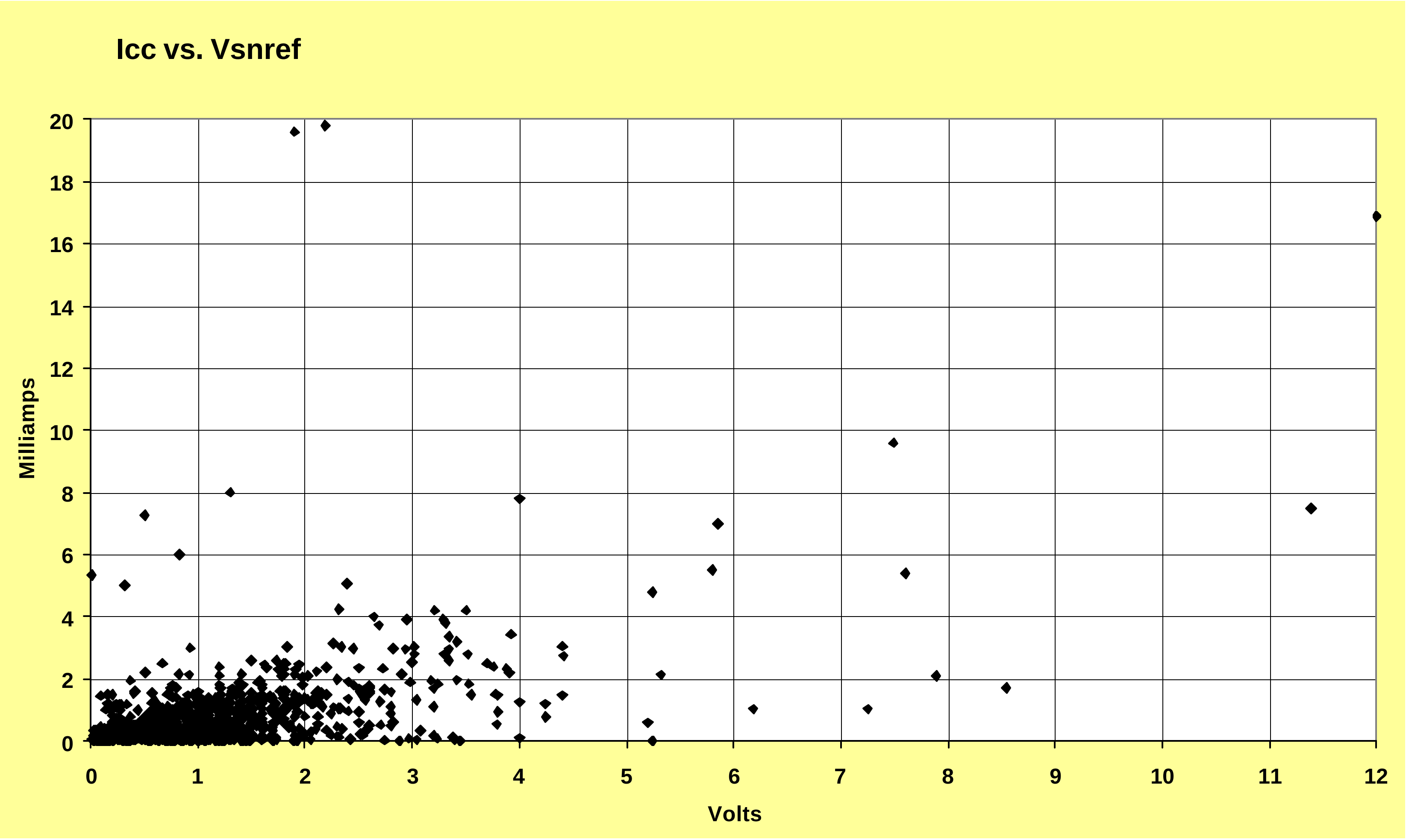

Icc vs. Vpnref
20
18
16
14
12
10
8
6
4
2
0
Milliamps
0
1
2
3
4
5
6
7
8
9
10
11
Volts

**FIGURE 7**



Icc vs. Vsnref
Milliamps
Volts
0
2
4
6
8
10
12
14
16
18
20
0
1
2
3
4
5
6
7
8
9
10
11
12


**FIGURE 8**

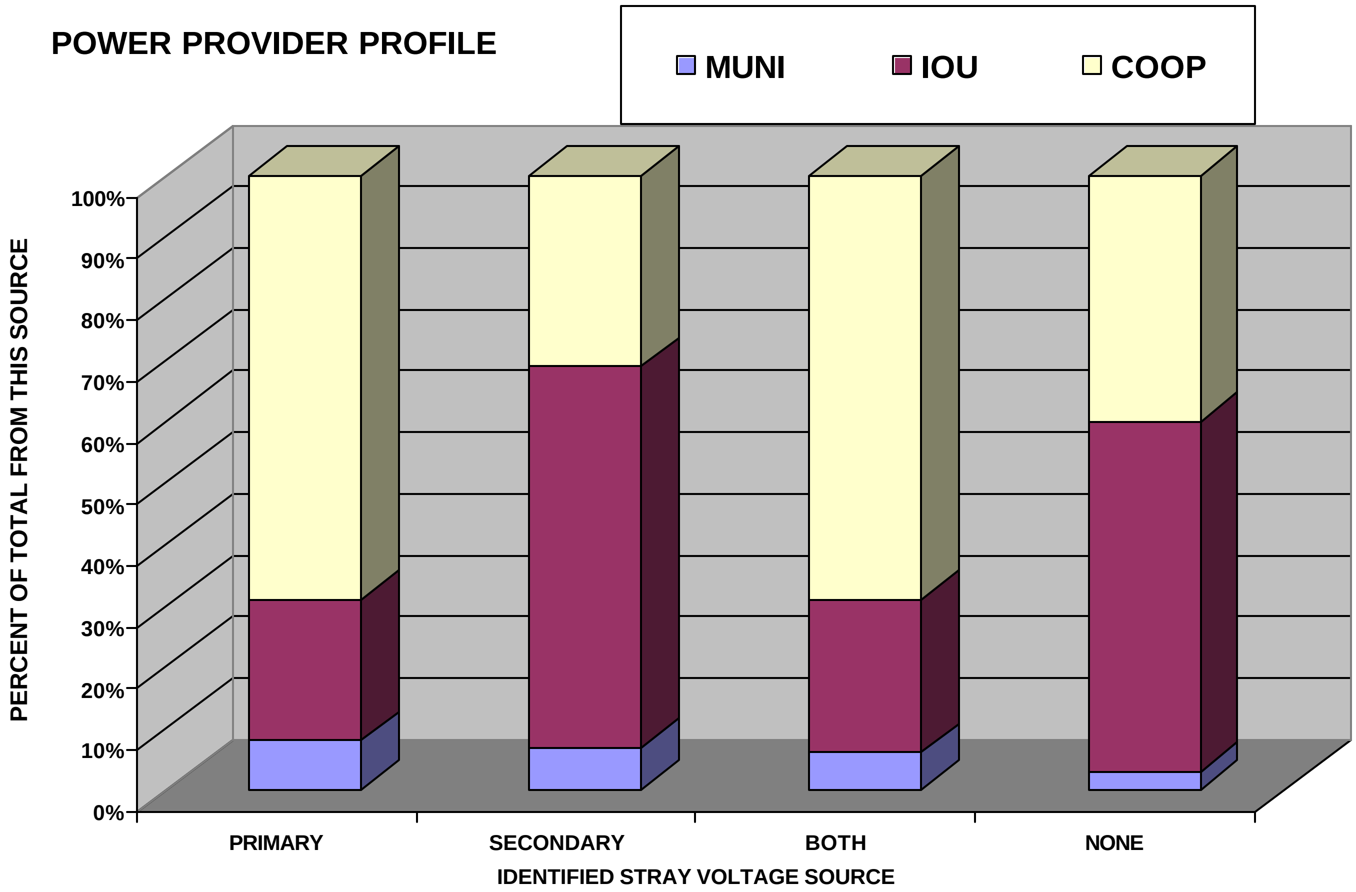

POWER PROVIDER PROFILE
MUNI
IOU
COOP
PERCENT OF TOTAL FROM THIS SOURCE
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
PRIMARY
SECONDARY
BOTH
NONE
IDENTIFIED STRAY VOLTAGE SOURCE

**FIGURE 9**

**POWER PROVIDER / STRAY VOLTAGE SOURCE**
**AVERAGE COW CONTACT DATA**

| | | UTILITY TYPE | | | |
|---|---|---|---|---|---|
| | **SV SOURCE** | **COOP** | **INV. OWNED** | **MUNICIPAL** | **ALL THREE COMBINED** |
| **Icc < 1 mA** | **NONE** | **0.44 ± 0.88 (35, 0.001 – 0.9)** | **0.30 ± 0.21 (50, 0.01 – 0.84)** | **0.28 ± 0.05 (3, 0.22 – 0.35)** | **0.36 ± 0.25 (88, 0.001 – 0.9)** |
| **Icc = 1 mA** | **PRIMARY** | **1.62 ± 0.51 (18, 1.0 – 2.8)** | **1.90 ± 0.77 (6, 1.0-3.0)** | **1.72 ± 0.08 (2, 1.64 – 1.8)** | **1.69 ± 0.57 (26, 1.0 – 3.0)** |
| | **SECONDARY** | **1.78 ± 0.23 (4, 1.45 – 2.11)** | **3.26 ± 2.38 (8, 1.0 – 7.03)** | **3.88 ± 0 (1, 3.88 – 3.88)** | **2.85 ± 2.01 (13, 1.0 – 7.03)** |
| | **BOTH PRIMARY AND SECONDARY** | **2.11 ± 1.03 (11, 1.0 – 4. 0)** | **1.94 ± 0.99 (4, 1.0 – 3.6** | **1.10 ± 0 (1, 1.1 – 1.1)** | **2.00 ± 1.01 (16, 1.0 – 4.0)** |
| | **ALL SOURCES** | **1.8 ± 0.74 (33, 1.0 – 4.0)** | **2.51 ± 1.84 (18, 1.0 – 7.03)** | **2.11 ± 1.06 (4, 1.0 – 3.88)** | **2.06 ± 1.27 (55, 1.0 – 7.03)** |

From SVAT database 2/27/1995
**Data Format: Mean ± std deviation**
**(no. of points, min – max)**

**FIGURE 10**

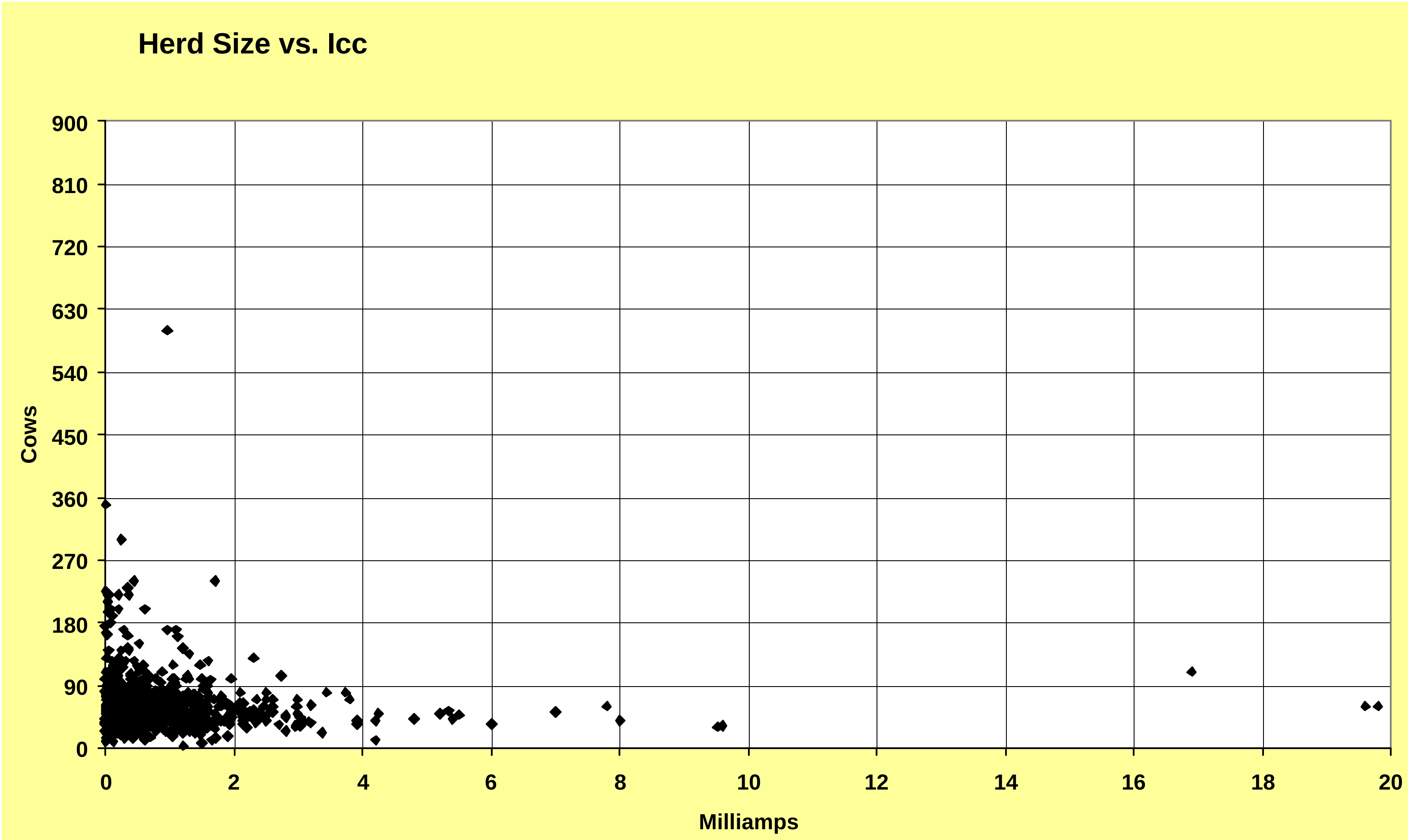

Herd Size vs. Icc
Cows
900
810
720
630
540
450
360
270
180
90
0
0
2
4
6
8
10
12
14
16
18
20
Milliamps

**FIGURE 11**

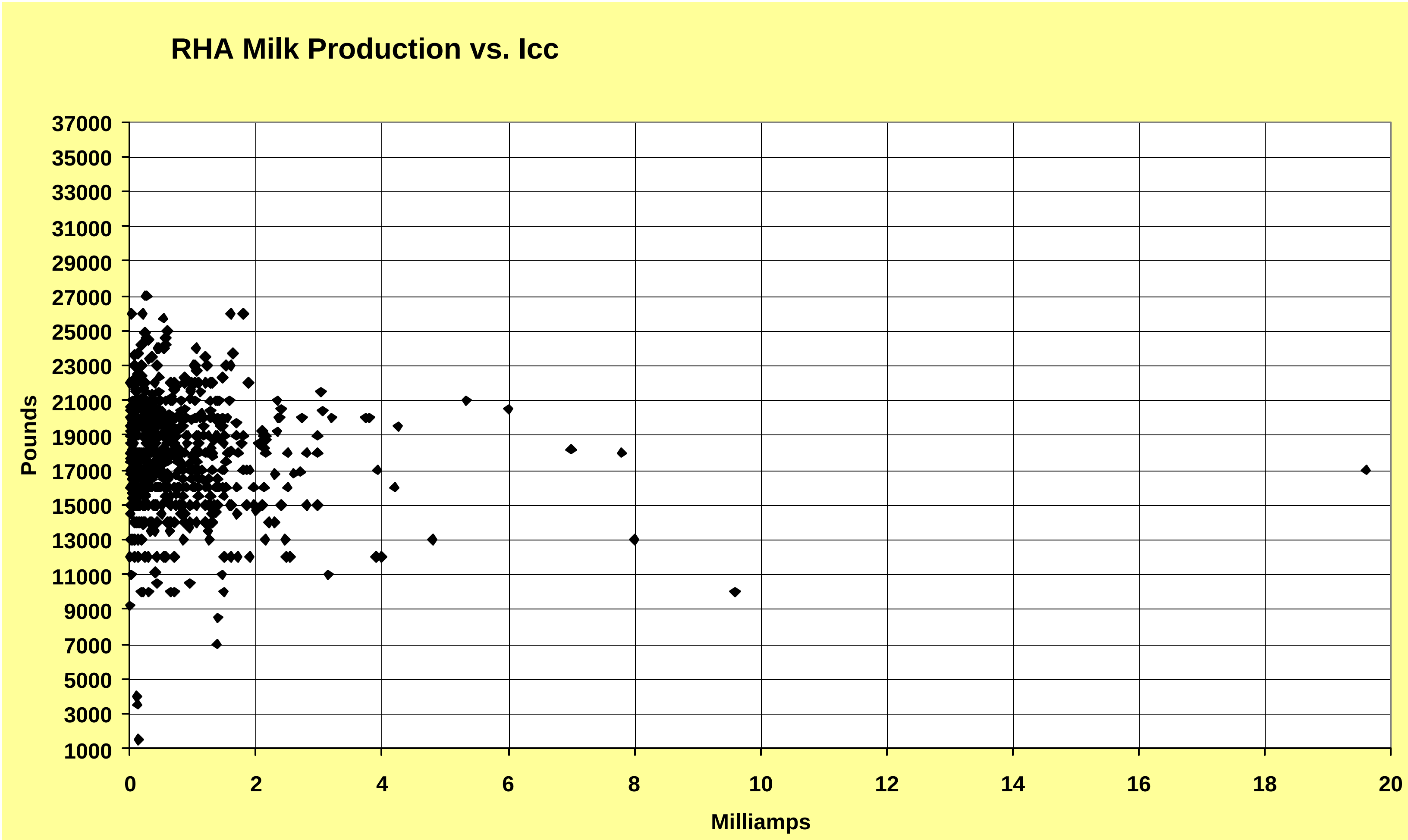
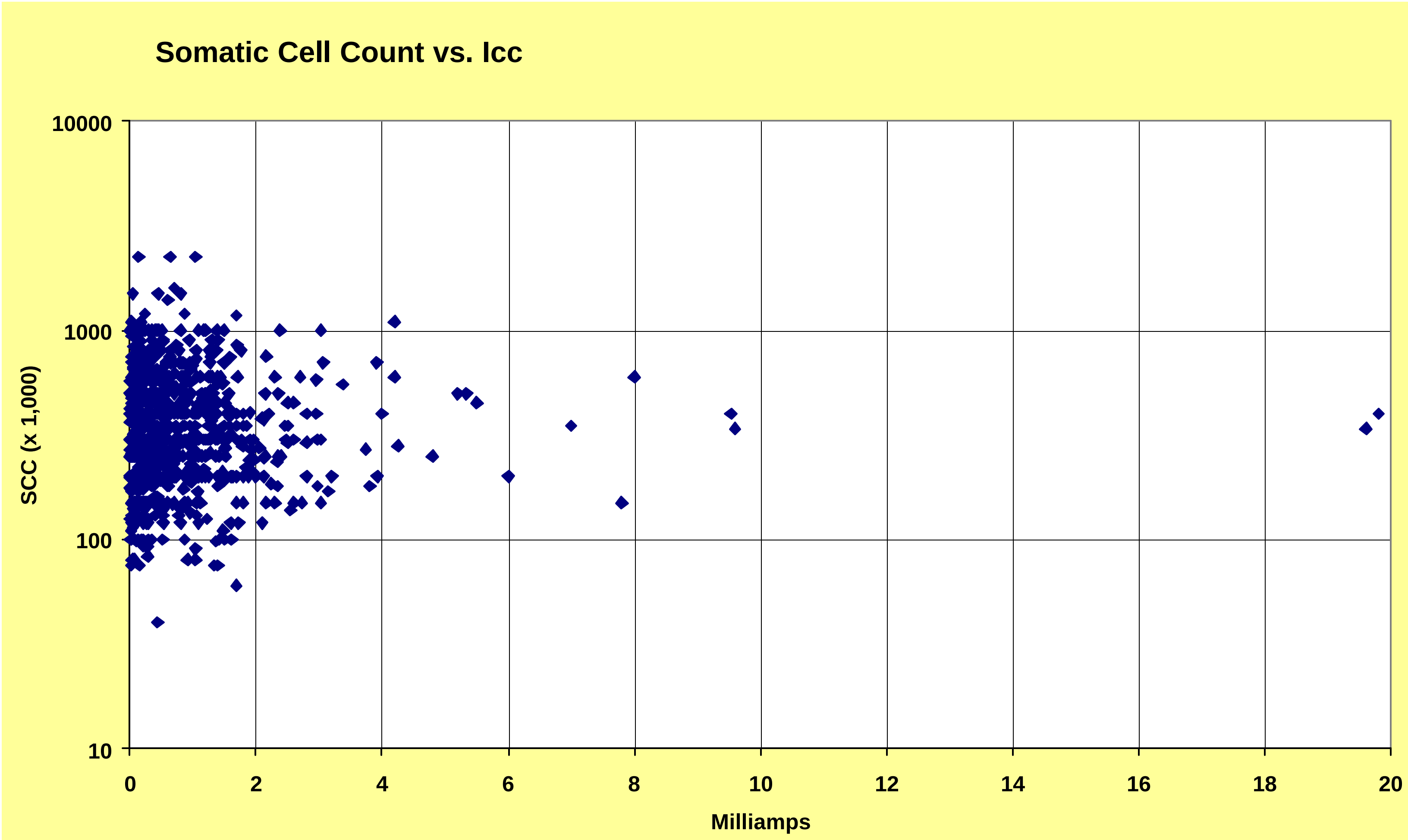

RHA Milk Production vs. Icc
Pounds
37000
35000
33000
31000
29000
27000
25000
23000
21000
19000
17000
15000
13000
11000
9000
7000
5000
3000
1000
0
2
4
6
8
10
12
14
16
18
20
Milliamps

**FIGURE 12**



Somatic Cell Count vs. Icc
10000
1000
100
10
SCC (x 1,000)
0
2
4
6
8
10
12
14
16
18
20
Milliamps


**FIGURE 13**